BAND SPECTRUM OF BISMUTH MONOCHLORIDE

By SANTI KUMAR RAY

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Plate IV

ABSTRACT. The band spectrum of bismuth chloride has been photographed both in emission and in absorption. A number of new bands has been discovered and is found to form a part of the existing less refrangible system of BiCl. The correctness of the vibrational analysis of Morgan for the two band systems of BiCl is confirmed.

INTRODUCTION

It is now well known from the recent work of Morgan[1] that bismuth monochloride has two band systems with a common lower state. One of them lies in the blue-green region between λ4300-λ5400 and consists of bands degraded towards the longer wave-lengths. The other system comprises bands in the violet region between λ3600-λ4000 and shows perturbations in the upper state. The direction in which these bands degrade is uncertain but they look somewhat diffuse on the red side. The two systems have been designated by Morgan as the less refrangible and the more refrangible system respectively.

In the course of an investigation conducted with the object of identifying the bands of bismuth monoxide, a number of new bands due to bismuth monochloride has been observed in the region λ4300-λ5700. They are quite distinct in appearance from the oxide bands which lie in the longer wavelength side of λ5400 and are partially resolved even with the dispersion of Hilger E.1 quartz spectrograph in this region. Like the bands of the less refrangible system of BiCl, they are entirely absent in the spectrum of the flaming arc fed with pure metallic bismuth, but appear intense when the arc is fed with solid bismuth trichloride. It may, however, be noted that sometimes they are weakly developed in the spectrum of the flaming arc fed with metallic bismuth, evidently due to the presence of the subchloride as an impurity in the metal. That these new bands are due to bismuth monochloride is further evidenced from the fact that several of them show isotopic heads due to $BiCl^{35}$ and $BiCl^{37}$ in their expected positions. This alone is sufficient to prove the identity of their emitter beyond any doubt. The object of the present paper is to report the vibrational quantum analysis of these bands.

EXPERIMENTAL

For source of emission of the BiCl bands, the flame surrounding a carbon arc running from 220V. d.c. mains and taking a current of about 3A was used. The lower electrode (+) of the arc had a cavity which was filled with solid $BiCl_3$ and fed with it at regular intervals during exposure.

To obtain these bands in absorption, light from a Philips 500-watt projection lamp was passed through the vapour obtained by heating solid $BiCl_3$ in an open iron tube contained in an electric resistance furnace and then focussed on the slit of the spectrograph. The iron tube had a length of 70 cms., an internal diameter of 1.6 cms., and a wall thickness of 0.25 cm. It was held coaxially inside the furnace whose ends were properly insulated to minimise the loss of heat. When the temperature inside the furnace was about 800°C., only the bands of the more refrangible system began to appear while when the temperature was more than about 1000°C., bands of both the systems made their appearance. At about 1100°C., they were very excellently developed.

A Fuess quartz prism spectrograph of large light-gathering power was used for preliminary observations. Hilger E.1 quartz spectrograph and E. 52 glass spectrograph as well as a 6-ft. concave grating spectrograph on a Paschen mounting were used for obtaining plates for measurements Ilford Hypersensitive (HP 2) and Empress plates were used. For comparison, iron arc lines were photographed.

Measurements were done on a Precision type Gaertner comparator (M101). Several sets of measurements were taken. In no case the individual wave-length of a band head differed from the average value by more than ±0.01A.

THE LESS REFRANGIBLE BAND SYSTEM

The bands of this system were known to the early investigators, but until recently there existed considerable doubt regarding their emitter. Eder and Valenta,[2] who had photographed the flame spectrum of various bismuth compounds, recorded as many as twenty-two of these band heads in the region λ4350-λ4935, but attributed them to the oxide of the metal Mecke and Guillery[3] were also of the same opinion. Using the data of the above authors they attempted at a vibrational quantum analysis of these bands and ascribed them to the diatomic molecule of bismuth monoxide. A different view was, however, put forward by Saper[4] who excited them by introducing vapour from heated $BiCl_3$ into active nitrogen and attributed the band system to the diatomic molecule of bismuth monochloride. Saper substantiated his assignment from observations of a vibrational isotope shift in agreement with the expected shift for Cl=35 and Cl=37 in some of the bands. In 1933 Ghosh,[5] who had not evidently taken notice of Saper's work, photographed these bands in the spectrum of a flaming

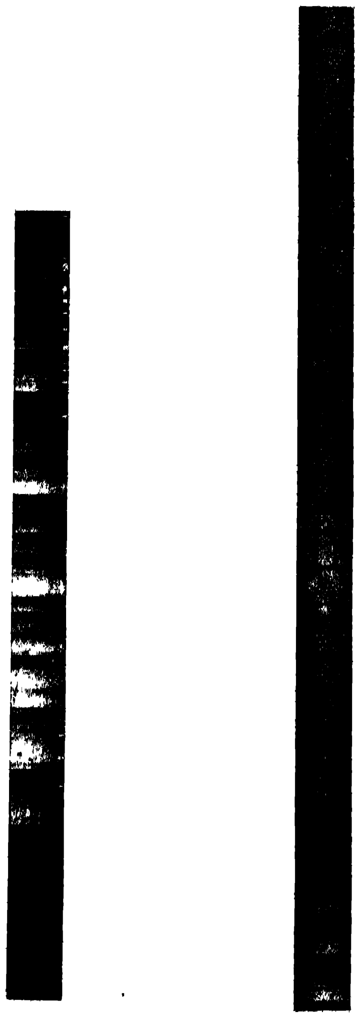
(a) (b)

Fig. I.

(a) A portion of the less refrangible system
(b) A portion of the more refrangible system

are fed with either metallic bismuth or bismuth trichloride and attributed them to bismuth monoxide. These conflicting views regarding the identity of their emitter led Morgan to investigate the spectrum of bismuth trichloride in absorption. For the source of absorption, he used the vapour from solid $BiCl_3$ heated at a temperature sufficiently high to vaporise bismuth trichloride and dissociate it to form BiCl. The spectrum was also developed when chlorine gas was passed over the molten metal. Using spectrographs of different dispersions, Morgan measured about eighty-two band heads in the region $\lambda 4300$-$\lambda 5400$ and carried out their vibrational analysis. Besides obtaining a satisfactory conformation of isotope theory, he noticed marked similarity of this band system to the corresponding band system of BiF and BiBr and confirmed Saper's view that its emitter is the diatomic molecule of bismuth monochloride.

In the present investigation, in addition to the bands recorded by Morgan, a large number of new bands has been added to the system, a portion of which is reproduced in Fig. 1(a). It is found from an analysis of their vibrational structure that some of these bands belong to the higher members of the different sequences observed by Morgan while others form new negative sequences of the system in question.

The band head data for the complete system are given in Table I which includes observed wave-length and wave-number data of heads together with their estimated relative intensities (given in parentheses) and vibrational quantum assignments. The last column of the table contains the wave-number data of band heads recorded by Morgan and his estimated intensities. The v', v''-values of band heads due to the less abundant isotopic molecule, $BiCl^{37}$, are marked with asterisks. The differences between wave-numbers observed and those calculated from Morgan's equations are also given. It may be noted here that the deviations in the case of the new bands are well within the limits of experimental error. This shows evidently the correctness of not only the vibrational quantum assignments to the new bands but also of the vibrational constants in the band head equations evaluated by Morgan. His equations are as follows :

$$BiCl^{35}: \quad \nu = 21801.8 + \{220.3(v'+\tfrac{1}{2}) - 2.50(v'+\tfrac{1}{2})^2\} - \{308.4(v''+\tfrac{1}{2}) - 0.96(v''+\tfrac{1}{2})^2\}$$

$$BiCl^{37}: \quad \nu = 21801.8 + \{215.1(v'+\tfrac{1}{2}) - 2.38(v'+\tfrac{1}{2})^2\} - \{301.2(v''+\tfrac{1}{2}) - 0.92(v''+\tfrac{1}{2})^2\}$$

It is only for the band head at 20283.5ν that the present assignment of v', v''-values is different from that of Morgan. Although the observed wave-number is equally close to the calculated wave-number of the band heads, (6, 9) and (3, 7), it is assigned to the latter from a consideration of the intensity distribution among the band heads of the system.

The intensities of the band heads have been estimated on a 0 to 8 scale. They lie on a well-defined and wide Franck-Condon parabola (Fig. 2).

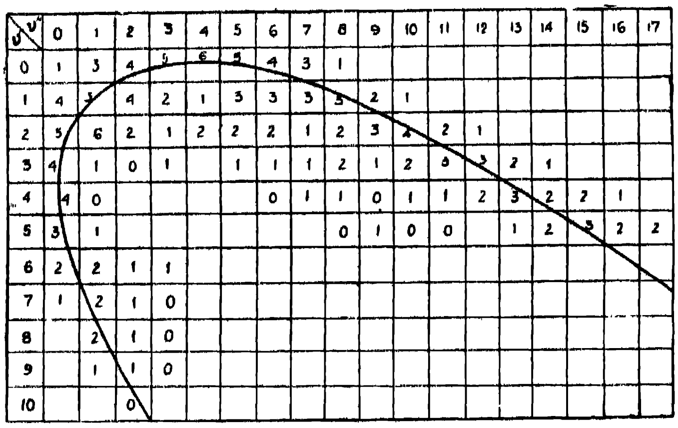

FIG. 2

It may be noted here that the band head, (9, 0), recorded by Morgan on the shorter wave-length side of this system has not been observed although there are a number of fairly intense bands, due presumably to BiO, present in the region λ4000-λ4300.

TABLE I

Band head data of the less refrangible system

v', v''	λ (I.A.)	$\nu_{vac.}$ (cm.$^{-1}$)	O—C (cm^{-1})	Morgan's wave-number data
9,1	4308.00(1)	23206.1	−2.5	...
7,0	16.70(1)	159.4	−0.1	23158.3(1)
* 7,0	22.11(0)	130.4	−0.4	125.1(0)
10,2	32.19(0)	076.5	2.2	071.3(1)
8,1	40.19(2)	034.0	0.7	031.0(2)
* 8,1	45.06(0)	008.2	−0.3	005.7(0)
6,0	51.79(2)	22972.6	−1.6	22971.1(3)
* 6,0	56.64(1)	947.0	−2.0	946.0(1)
9,2	64.80(1)	904.1	0.1	906.0(1)
* 9,2	69.08(0)	881.7	−1.5	882.1(0)
7,1	74.44(2)	853.7	0.7	849.6(3)
* 7,1	78.25(1)	833.8	2.3	828.1(1)
5,0	87.85(3)	783.9	0.0	783.4(4)

TABLE I (*contd.*)

v', v''	λ (I.A.)	$\nu_{vac.}$ (cm.$^{-1}$)	O—C (cm.$^{-1}$)	Morgan's wave-number data
*5,0	4392.30(1)	22760.7	−1.8	22760.1(1)
8,2	99.08(1)	725.8	−2.9	727.0(1)
*8,2	4402.56(0)	707.7	−3.3	706.6(0)
6,1	10.38(2)	667.4	−0.3	665.2(2)
*6,1	13.79(1)	649.9	0.2	647.1(1)
9,3	23.50(0)	600.2	−1.2	
4,0	25.89(4)	588.0	−0.6	588.4(8)
*4,0	29.20(2)	571.1	−0.1	571.5(3)
7,2	33.46(1)	549.4	1.0	
5,1	47.71(1)	477.2	−0.2	476.0(2)
8,3	57.70(0)	426.8	0.7	...
3,0	65.26(4)	388.9	0.6	388.1(10)
*3,0	68.12(2)	374.5	−0.6	374.5(4)
6,2	70.38(1)	363.2	0.1	...
4,1	86.90(0)	280.9	−1.2	...
7,3	94.14(0)	245.0	−0.8	...
2,0	4506.72(5)	182.9	−0.1	182.8(7)
*2,0	*08.44(2)	174.4	0.1	176.7(2)
5,2			1.6	
3,1	27.35(1)	081.8	0.0	081.7(1)
*3,1	28.77(0)	074.9	−0.9	071.4(0)
6,3	31.72(1)	060.5	0.0	...
1,0	49.92(4)	21972.3	−0.4	21972.3(5)
2,1	69.91(6)	876.2	−0.3	876.4(10)
3,2	90.68(0)	877.2	0.0	...
0,0	95.06(1)	756.4	−1.0	756.2(1)
*1,1	4613.43(3)	669.8	0.4	670.4(3)
1,1	14.38(8)	665.3	−0.9	666.0(10)
*2,2	33.20(1)	577.3	−0.1	576.2(0)

TABLE I (*contd.*)

v', v''	λ (I.A.)	$\nu_{vac.}$ (cm.$^{-1}$)	O—C (cm.$^{-1}$)	Morgan's wave-number data
2,2	4634.30(2)	21572.2	0.3	21572.1(0)
3,3	55.25(1)	475.1	0.4	475.4(4)
0,1*	58.64(1)	459.5	0.5	459.5(2)
0,1	60.35(3)	451.6	0.7	450.8(5)
1,2*	77.83(2)	371.6	−0.3	372.1(3)
1,2	80.07(4)	361.2	−0.4	361.5(7)
2,3*	97.95(0)	279.9	−1.9	...
2,3	4700.40(1)	268.9	−0.4	...
0,2*	24.40(1)	160.8	−0.7	162.2(3)
0,2	27.62(4)	146.1	0.1	146.7(8)
1,3*	43.58(1)	075.2	−1.0	074.6(1)
1,3	47.51(2)	057.8	−1.6	058.3(2)
2,4*	62.67(1)	990.8	2.9	...
2,4	67.80(2)	968.2	−0.4	20969.8(1)
3,5*	4783.69(0)	898.5	1.8	...
3,5	88.50(1)	877.5	2.4	...
0,3*	91.22(2)	865.7	−0.1	866.0(3)
0,3	96.34(5)	843.4	0.0	843.9(9)
4,6	4810.81(0)	780.7	2.2	...
1,4	16.30(1)	757.0	−1.3	...
2,5*	30.57(1)	695.7	−0.2	...
2,5	36.62(2)	669.8	0.0	669.6(1)
3,6*	51.62(0)	606.0	−0.7	...
3,6	58.25(1)	577.8	−0.4	578.3(0)
0,4*	59.58(3)	572.2	0.2	572.2(3)
0,4	66.42(6)	543.2	0.2	543.1(7)
4,7*	73.26(0)	514.4	0.1	...
1,5*	79.00(1)	490.3	0.0	...
4,7	80.63(1)	483.5	0.0	...

TABLE I (*contd.*)

v', v''	λ (I.A.)	$\nu_{vac.}$ (cm.$^{-1}$)	O—C (cm.$^{-1}$)	Morgan's wave-number data
1,5	4886.35(3)	20459.5	0.0	...
5,8*	96.02(0)	419.1	0.0	...
2,6*	99.53(0)	404.4	−1.4	...
5,8	4903.98(0)	385.9	0.1	...
2,6	07.20(2)	372.5	−0.4	...
3,7*	20.46(0)	317.6	−0.7	...
3,7	28.74(1)	283.5	0.3	20284.3(0)
0,5*	29.70(3)	279.6	−0.4	280.6(3)
0,5	38.40(5)	243.8	0.6	244.5(6)
1,6*	49.10(1)	200.1	−0.1	...
4,8	51.65(1)	189.7	−0.8	190.0(1)
1,6	58.18(3)	163.1	0.5	163.5(2)
5,9*	64.67(0)	136.7	2.2	...
2,7*	69.60(0)	116.7	−0.7	...
5,9	4974.63(1)	096.4	1.7	095.0(1)
2,7	79.58(1)	076.4	−1.5	...
3,8*	90.95(0)	036.7	−1.1	...
3,8 0,6*	5000.76(2)	19991.4	1.2 1.6	19991.1(1)
0,6	11.64(4)	948.0	0.7	948.2(4)
1,7*	20.72(2)	911.9	0.0	911.2(1)
4,9	23.85(0)	899.5	0.1	898.0(0)
1,7	32.07(3)	867.0	−0.6	868.3(3)
2,8*	41.25(1)	830.8	−0.1	...
5,10	47.68(0)	805.6	0.1	805.0(1)
2,8	52.96(2)	784.9	0.0	785.0(0)
0,7* 3,9	74.29(1)	701.7	0.2 2.6	702.2(1)
4,10*	84.39(0)	662.6	2.2	...

TABLE I (*contd.*)

v, v''	λ (I.A.)	$\nu_{vac.}$ (cm.$^{-1}$)	O—C (cm $^{-1}$)	Morgan's wave-number data
0,7	5087.12(3)	19652.0	−0.3	19653.5(2)
1,8*	93.64(2)	626.9	1.5	...
4,10	97.92(1)	610.4	0.2	...
1,8	5100.38(5)	574.1	−0.5	575.0(2)
2,9*	14.53(1)	546.7	0.4	548.0(1)
5,11	21.82(0)	518.9	0.7	...
2,9	28.37(3)	494.0	0.2	494.0(2)
3,10*	36.00(0)	465.0	0.7	...
3,10	50.58(2)	409.9	0.0	410.0(2)
0,8	64.23(1)	358.6	−0.7	360.0(1)
1,9*	69.40(1)	339.2	−1.5	...
4,11	73.78(1)	322.9	0.0	322.0(0)
1,9	84.15(2)	284.2	0.7	284.0(2)
2,10*	5189.59(1)	264.0	0.5	262.0(1)
2,10	5205.72(4)	204.3	−0.3	204.0(2)
3,11*	11.77(1)	182.0	−1.4	...
3,11	27.80(3)	123.2	0.6	124.0(0)
4,12	51.32(2)	037.5	0.0	037.0(1)
1,10	63.36(1)	18994.0	−0.3	18994.0(1)
2,11*	60.56(1)	982.4	−0.2	...
5,13	75.96(1)	948.6	−0.8	947.0(1)
2,11	84.85(2)	916.8	−0.5	917.0(1)
3,12*	88.33(1)	904.3	0.0	...
6,14	5301.40(0)	857.7	−0.1	...
3,12	07.20(3)	837.1	−0.1	837.0(1)
4,13*	11.40(1)	822.2	−0.8	...
4,13	30.69(3)	754.1	0.0	754.0(0)
2,12*	45.14(0)	703.4	0.0	...
51,4	55.23(2)	668.2	0.4	...

TABLE I (*contd.*)

v', v''	λ (I.A.)	$\nu_{vac.}$ (cm.$^{-1}$)	O—C (cm.$^{-1}$)	Morgan's wave-number data
2,12	5365.41(1)	18632.7	0.8	...
6,15	81.22(1)	578.0	−0.5	...
3,13	88.34(2)	553.4	−0.4	18552.0(0)
4,14	5411.80(2)	473.0	0.4	...
5,15	36.70(3)	388.4	0.1	...
*3,14	47.92(0)	350.5	−1.0	...
6,16	63.00(2)	299.9	−1.0	...
3,14	71.20(1)	272.5	0.2	...
7,17	90.20(1)	209.2	−1.2	...
4,15	94.90(2)	193.7	0.7	...
5,16	5520.10(2)	110.6	0.0	...
6,17	46.38(2)	024.8	−0.3	...
7,18	74.18(2)	17934.9	−1.7	...
4,16	5580.06(1)	916.0	−0.7	...
5,17	5605.47(2)	834.8	0.0	...
6,18	32.55(2)	749.0	−2.3	...
7,19	60.52(1)	661.3	−3.4	...

THE MORE REFRANGIBLE BAND SYSTEM

The bands of this system have been for the first time investigated in detail by Morgan [1] in absorption. He has measured and analysed about one hundred band heads in the region λ3600-λ4000. Previously Eder and Valenta [2] had recorded only the approximate measurements of a group of five line-like heads in the neighbourhood of λ3900 in the flame spectrum of a bismuth compound. This group represents the sequence, $\Delta\nu = 0$. Morgan has also identified the isotopic heads due to $BiCl^{35}$ and $BiCl^{37}$, thereby confirming the identity of their emitter beyond any doubt.

In the present investigation, a few new bands due to the less abundant molecule $BiCl^{37}$ have been measured at the longer wave-length side of this band system. On the other hand, the band heads, which Morgan recorded on the shorter wave-length side of λ3654, could not be detected on the plates taken by the present author.

When the bands are arranged in a Deslandres scheme, it is found that while the interval between the successive vibrational levels in the lower state decreases practically at a constant rate, that in the upper state does not. This shows that

v' \ v''	0	1	2	3	4	5	6	7	8	9	10
0	10										
1	6	9	2	1							
2	4	5	6	3	1						
3	1	4	5	6	0	4					
4	0	3	4	4	5	4	4				
5		0	3	4	4	3	0	2			
6			1	4	3	2	2	2			
7				1	3	3	[illegible]	1	2		
8					1	7	2	0	0	0	
9						1	1	2	00		
10							0	1	1		

FIG. 3

a third power term in $(v'+\frac{1}{2})$ is necessary to represent the vibrational levels in the upper state. Hence the equations of Morgan have been modified to represent the observed data of band heads for this system. These equations are as follows :

$$\text{BiCl}^{35}: \quad \nu = 25492.7 + \{403.50(v'+\tfrac{1}{2}) - 3.768(v'+\tfrac{1}{2})^2 + 0.0016(v'+\tfrac{1}{2})^3\}$$
$$- \{307.66(v''+\tfrac{1}{2}) - 0.954(v''+\tfrac{1}{2})^2\}$$

$$\text{BiCl}^{37}: \quad \nu = 25492.7 + \{394.02(v'+\tfrac{1}{2}) - 3.593(v'+\tfrac{1}{2})^2 + 0.0015(v'+\tfrac{1}{2})^3\}$$
$$- \{300.45(v''+\tfrac{1}{2}) - 0.910(v''+\tfrac{1}{2})^2\}.$$

The band head data for the complete system are given in Table II and are arranged in a way similar to that in Table I for the less refrangible system. It will be seen that the O-C values are in most cases within the limits of experimental error.

The intensities of the band heads for this system have been estimated on a 0 to 10 scale. As in the case of the less refrangible system, there is a divergence of the intensity data of Morgan from those given here. The intensity distribution is similar to that obtained by Morgan for the more refrangible band system of BiBr and lies on a well-defined narrow Condon parabola.

TABLE II

Band head data of the more refrangible system

v', v''	λ (I.A.)	$\nu_{vac.}$ (cm.$^{-1}$)	O−C (cm.$^{-1}$)	Morgan's wave-number data
10, 6	3654.28 (0)	27357.4	1.1	27358.0 (1)
9, 5	58.56 (1)	325.4	1.4	325.4 (2)
9, $\overset{*}{5}$	63.53 (0)	288.3	0.0	288.3 (0)
8, 4	63.83 (1)	286.1	0.1	285.7 (1)
8, $\overset{*}{4}$	68.89 (0)	248.5	−1.4	248.3 (0)
7, 3	69.63 (1)	243.0	0.5	240.8 (1)
7, $\overset{*}{3}$	74.65 (0)	205.8	−0.3	203.8 (0)
6, 2	76.43 (1)	192.6	−0.9	191.6 (1)
6, $\overset{*}{2}$	81.41 (0)	155.8	−1.3	154.4 (0)
5, 1	83.85 (0)	137.8	−1.0	137.3 (1)
5, $\overset{*}{1}$	88.72 (00)	102.0	−0.8	100.7 (00)
4, 0	92.03 (0)	077.7	−1.0	077.7 (00)
10, 7	94.18 (1)	061.9	−0.1	063.2 (1)
10, $\overset{*}{7}$	98.00 (0)	034.0	−0.1	034.0 (0)
9, 6	98.82 (1)	028.0	0.3	028.7 (2)
9, $\overset{*}{6}$	3702.86 (0)	26998.5	−0.4	26998.5 (1)
8, 5	04.43 (2)	987.4	−0.5	987.2 (2)
8, $\overset{*}{5}$	08.28 (1)	959.0	0.4	956.7 (1)
7, 4	10.58 (3)	942.3	−0.2	940.6 (2)
7, $\overset{*}{4}$	14.93 (1)	910.8	−2.2	910.3 (1)
6, 3	17.62 (4)	891.3	−0.2	889.2 (2)
6, $\overset{*}{3}$	21.95 (1)	860.0	−2.2	859.2 (1)
5, 2	25.43 (3)	834.9	−0.1	833.1 (2)
5, $\overset{*}{2}$	29.58 (1)	805.1	−0.9	803.6 (1)
4, 1	33.98 (3)	773.5	0.6	772.1 (2)
10, 8	34.46 (0)	770.0	0.4	770.5 (1)
10, $\overset{*}{8}$	37.58 (0)	747.7	−0.6	747.5 (0)
4, $\overset{*}{1}$	37.99 (0)	744.8	0.2	743.3 (1)

TABLE II (*contd.*)

v', v''	λ (I.A.)	$\nu_{vac.}$ (cm.$^{-1}$)	O−C (cm.$^{-1}$)	Morgan's wave-number data
9, 7	3739.54 (2)	26733.7	0.3	26733.8 (2)
9, $\overset{*}{7}$	42.77 (0)	710.6	−0.8	710.4 (1)
3, 0	43.57 (1)	704.9	−0.4	705.9 (2)
8, 6	45.40 (2)	691.2	−0.4	690.7 (3)
3, $\overset{*}{0}$	47.35 (0)	678.0	0.2	678.0 (0)
8, $\overset{*}{6}$	48.72 (1)	668.2	−0.4	666.8 (1)
7, 5	52.10 (3)	644.2	−0.2	642.1 (3)
7, $\overset{*}{5}$	55.54 (1)	619.8	−1.9	618.4 (1)
6, 4	59.61 (3)	591.0	−0.5	588.7 (3)
6, $\overset{*}{4}$	62.97 (1)	567.2	−1.9	565.6 (1)
5, 3	67.85 (4)	532.8	−0.2	530.9 (4)
5, $\overset{*}{3}$	71.14 (2)	509.7	−1.4	508.3 (2)
4, 2	76.96 (4)	468.8	−0.3	467.9 (4)
4, $\overset{*}{2}$	80.10 (2)	446.8	−1.0	446.2 (1)
9, 8	81.00 (00)	440.5	−0.5	441.5 (00)
3, 1	86.85 (4)	399.7	0.2	399.7 (3)
8, 7	87.28 (0)	396.7	−0.6	396.6 (0)
3, $\overset{*}{1}$	89.84 (2)	378.9	−0.3	379.0 (2)
7, 6	94.38 (1)	347.3	−0.8	345.7 (2)
7, $\overset{*}{6}$	96.80 (0)	330.5	−1.8	328.9 (1)
2, 0	97.54 (4)	325.4	1.1	325.7 (4)
2, $\overset{*}{0}$	3800.34 (1)	306.0	0.7	306.3 (2)
6, 5	02.42 (2)	291.6	−1.8	290.5 (3)
6, $\overset{*}{5}$	04.74 (0)	275.6	−2.2	274.2 (1)
5, 4	11.09 (4)	231.8	−1.2	230.7 (3)
5, $\overset{*}{4}$	13.45 (1)	215.6	−2.4	215.0 (2)
4, 3	20.56 (4)	166.8	−0.3	166.0 (4)
4, $\overset{*}{3}$	22.78 (3)	152.6	−0.3	151.2 (2)
8, 8	29.78 (0)	103.8	−1.1	103.8 (1)
3, 2	30.92 (5)	096.0	0.3	096.0 (5)

TABLE II (*contd.*)

v', v''	λ (I.A.)	$\nu_{vac.}$ (cm.$^{-1}$)	O − C (cm.$^{-1}$)	Morgan's wave-number data
3, $\overset{*}{2}$	3832.95 (3)	26082.2	−0.2	26082.2 (2)
7, 7	37.05 (1)	054.3	0.5	051.5 (3)
7, $\overset{*}{7}$	38.85 (0)	042.1	−2.7	041.1 (1)
2, 1	42.10 (5)	020.0	1.5	020.0 (5)
2, $\overset{*}{1}$	44.00 (3)	007.2	0.5	007.6 (2)
6, 6	45.53 (2)	25996.9	−0.2	25993.8 (1)
6, $\overset{*}{6}$	47.08 (0)	986.4	−2.0	984.1 (0)
1, 0	54.41 (6)	937.0	1.1	937.0 (6)
5, 5	54.90 (3)	933.7	−1.2	932.4 (2)
1, $\overset{*}{0}$	56.01 (3)	926.2	0.5	926.2 (3)
4, 4	65.00 (5)	865.9	−1.2	865.8 (6)
4, $\overset{*}{4}$	66.03 (4)	859.0	−0.8	858.0 (3)
8, 9	72.89 (0)	813.2	−1.1	812.9 (0)
8, $\overset{*}{9}$	73.25 (2)	810.8	−1.2	808.4 (0)
3, 3	75.77 (6)	794.0	0.3	794.0 (7)
3, $\overset{*}{3}$	76.80 (5)	787.2	−0.3	787.2 (4)
7, 8	80.86 (2)	760.2	−1.2	759.1 (0)
7, $\overset{*}{8}$	81.31 (0)	757.2	−1.8	755.4 (0)
2, 2	87.53 (6)	716.0	1.3	716.4 (8)
2, $\overset{*}{2}$	88.38 (7)	710.4	0.5	710.9 (4)
6, 7	89.54 (2)	702.7	−0.1	702.7 (1)
6, $\overset{*}{7}$	89.92 (1)	700.2	−0.7	700.2 (1)
5, 6	99.36 (0)	638.0	−0.6	636.6 (0)
1, 1	3900.27 (9)	632.0	1.9	632.0 (2)
1, $\overset{*}{1}$	00.96 (2)	627.5	0.4	628.1 (4)
4, 5	09.94 (4)	568.6	−0.4	568.5 (1)
0, 0	14.26 (10)	540.4	−0.5	539.9 (10)
3, 4	21.38 (0)	494.0	0.3	494.9 (0)
2, $\overset{*}{3}$	33.57 (0)	415.0	0.0	417.2 (0)
2, 3	34.01 (3)	412.2	−0.5	415.7 (1)

TABLE II (*contd.*)

v', v''	λ (I.A.)	$\nu_{vac.}$ (cm.$^{-1}$)	O−C (cm.$^{-1}$)	Morgan's wave-number data
5, 7*	3943.75 (0)	25349.4	−0.4	—
5, 7	44.53 (2)	344.4	0.1	25344.4 (0)
1, 2	47.08 (2)	328.0	1.7	328.6 (0)
4, 6*	54.58 (0)	280.0	0.9	—
4, 6	55.64 (4)	273.2	0.5	273.8 (0)
3, 5*	66.57 (0)	203.6	0.5	—
3, 5	67.61 (4)	197.0	1.4	197.5 (0)
2, 4*	79.26 (0)	123.2	1.3	—
2, 4	80.85 (1)	113.2	0.5	113.5 (0)
1, 3*	93.18 (1)	035.6	0.2	—
1, 3	94.96 (1)	024.5	0.2	024.9 (0)

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SPECTROSCOPIC LABORATORIES,
APPLIED PHYSICS DEPARTMENT

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